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Second Quarterly Technical Report
June 30, 1972

Bioengineering Study of Basic Physical Measurements Related to Susceptibility to Cervical Hyperextension-Hyperflexion Injury

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BIOENGINEERING STUDY OF BASIC PHYSICAL MEASUREMENTS RELATED TO SUSCEPTIBILITY TO CERVICAL HYPEREXTENSION-HYPERFLEXION INJURY

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SUMMARY

Work during the three-month period, April 1 through June 30, has been primarily concentrated on the problems of constructing the experimental equipment, refining the techniques and methods to be utilized, and preliminary analysis of the data. A major accomplishment was the acquisition of the necessary Ampex recorder and completion, installation, and checkout of all the experimental equipment. Due to the administrative delay in obtaining the recorder our schedule is somewhat behind the projected schedule in subject measurement for this milestone, although we are far ahead of projected accomplishments in literature searching. Some problems in measurement of cervical neuromuscular reaction times have been encountered which will require equipment and technique modifications. We anticipate that these can be corrected early in the next quarter; however, this will result in further revision of the projected schedule. Progress at this milestone may be briefly summarized as follows:

1. Continuing literature search has revealed 370 additional relevant publications, making a total of 1410 references to date, far in excess of our original estimate. These have been categorized in five main groups, and now include 148 references in cervical motion and mobility, 62 in mechanical injury, 233 related to cervical anatomy and radiology, 115 concerned with experimental cervical strength and stress, and the bulk, 852 references, related to clinical reports of cervical injury. A comparative analysis of the results of the additional 17 cervical motion studies found has been tabulated for reference.

2. Radiography of 17 subjects have now been taken; including one A-P 8 x 10 inch film, and four 10 x 12 inch lateral views of the subject in hyperextension, hyperflexion, and seated in a soft production seat and on a hard seat in standardized neutral seated positions.

3. The protocol has been revised slightly to further decrease subject risk. After medical approval based upon initial medical questionnaire, the subject is called in for first series of tests including five x-rays, at least 12 photographs and anthropometry. The strength and range of motion tests are done at a later time after the subject's x-ray films have been clinically examined.

4. The cervical measurement laboratory equipment layout and measurement stations have been modified for more efficient utilization.

5. Construction, acquisition, installation and checkout of all of the equipment has now been completed, with EMG, force and displacement channels verified.

6. For anthropometry a new seat has been designed and constructed to facilitate measurements. The eight measurements listed in the last report as being considered will be taken where possible, as optional.

7. A photogrammetry headpiece has been designed, fabricated and tested to be utilized for x-ray and photogrammetric analysis, with lead markers attached to provide accurate reference landmark orientations for any position of the head.

8. A reaction time headpiece has been designed, fabricated and tested which utilizes a triggering mechanism for a weight to measure reaction time in flexion and extension. Accelerometers attached to the headpiece detect instantaneous head accelerations.

9. A strength measurement apparatus has been designed, fabricated and tested to measure strength of neck extensor and flexor muscles.

10. Measurement procedures have been developed for the above tests.

11. Four subjects have been tested using the procedures and hardware described.

12. A preliminary data analysis has been completed for four subjects and results indicate that most of the measurement procedures are reliable and can be administered without modifications.

13. Where necessary, alternative procedures and equipment modifications have been initiated to increase the quality of the data.

I. INTRODUCTION

Neck injury commonly results to occupants of motor vehicles involved in rear-end collisions. Such trauma has been characterized as "whiplash" or hyperextension-hyperflexion injuries. However, recent field and clinical investigations indicate that there is a significant preponderance of "whiplash" symptoms among females. Little information is known concerning variation in head mass or center of gravity of the seated occupant or variation of neck muscle strength as related to age, sex, and physique differences, and no previous study has related variation in neck muscle response time to external acceleration stimulus. Such information would appear to be of basic importance in consideration of sensitivity to hyperextension-hyperflexion injury.

The primary objective of this study is to determine the range of physical variation in function and structure of the human neck, with variables of age, sex, and stature, as a basis for improved head protection design in vehicular occupant hyperextension-hyperflexion accidents. Specific tests and measurements are being designed and will be conducted to result in several major types of information relating to the range of physical and sexual variation of the neck in a representative U.S. population. Neck measurements to be determined include anthropometry, radiography, photogrammetry, muscle strength, voluntary range of extension and flexion cervical motion, and muscle response time. Mathematical modeling is being used to predict dynamic sensitivity to changes in the parameters developed.

The following technical progress report provides a brief review of the second 90-day period of this investigation. The status of accomplishments to date reflect final acquisition or fabrication, installation and check out of equipment, instrumentation and techniques necessary to undertake the subject measurements. Emphasis has been placed upon final design and construction of the necessary equipment such as specialized headpieces and fixtures, establishment of procedures, and preparations for the tests. Subject testing to date has been principally confined to radiography and anthropometry, with preliminary check outs of strength, muscle reaction time, and range of motion tests.

II. TASK PROGRESS

1. Literature Survey

A voluminous body of literature has been referenced to date related to the neck, although the majority of papers pertain to clinical aspects of trauma and treatment.

The bibliography included in this report has been divided into five general categories; motion/mobility, mechanisms of injury, injuries/ fractures, anatomy/radiography, and experimental strength and stress. As suspected, the bulk of the literature involves clinical reports not of particular use except to emphasize the nature and extent of cervical injuries.

Since the last reporting period we have located 370 additional references, bringing the total number of references found to date to 1410. The bibliography lists only these new acquisitions, and it is planned to combine and possibly restructure the categories for the final report. Thus each quarterly report will reflect the new references retrieved during that period, rather than the bulky total bibliography.

In the category "Motion/Mobility" 131 references were reported in the first quarterly report, and 17 additional reports are included at this time, bringing the total to 148 related to motion. To date, however, only 23 different studies of normal cervical motion have been located, and new data since the last report are tabulated in Table I. Many other motion studies in the literature were not considered because they utilized subjects with previous history of neck injury and could generate abnormal motion readings. Only two studies found in the "normal motion" literature use both male and female subjects over a wide age span, while the rest report measurements based upon a single sex, a limited age range and a selected sample. This confirms our initial findings of insufficient, inadequate, and/or unusable data from previous reports for application to this study.

Further, it is difficult to compare results because of the different techniques, measurements, and end-points employed by the various investigators. Extensions and flexion limits have only been identified in ten studies although all studies listed a range of motion measured in the sagittal plane alone. Combining the 1958 total subjects for all previous studies identified to date results in a mean range of sagittal motion of 130°. But it is obvious from examination of previous work that no thorough study of the basic parameters outlined in this investigation has been conducted for a large number of subjects representative of the general population and including both sexes for a wide age-span.

Additional references retrieved during this period have included 17 reports, for a total of 62 to date in the category of mechanical injury, 62, for a total of 233, related to cervical anatomy or radiological studies, 38, for a total of 115 references in the area of experimental strength or stress of cervical structures, and 236, totaling 852 clinical reports of injuries. Due to the reproduction expense which would be involved (of about $1,000), no attempt has been made to acquire copies of all of these references; however, selected pertinent reports are obtained as required.

A recent publication which appears to be of particular value in the analysis and understanding of hyperextension-hyperflexion mechanisms is entitled "Mechanism of Cervical Spine Injury in Auto Accidents," by H.D. Portnoy, J.H. McElhaney, J.W. Melvin and P.D. Corissant, Proceedings of the American Association for Automotive Medicine, SAE reprint, April,

TABLE I. A SUMMARY OF RESULTS OF 17 CERVICAL MOTION STUDIES IDENTIFIED IN THE LITERATURE DURING THIS REPORTING PERIOD.

REFERENCES	SEX	N	AGE	TOTAL FLEXION° & EXTENSION°	LATERAL FLEXION°	ROTATION°	COMMENTS
19.* Sigerseth	M	61		130.3°		170.0°	College football players
Sigerseth	M	39		132.5°		172.0°	College football players
Sigerseth	M	56		140.2°		174.8°	College students
20. Newell	M	48	18-40	146.5°	107.1°	169.2°	
21. Hinz						180.0°	All healthy patients
22. Jirout							Excellent analysis of latero-flexion mechanism
23. Bendixen							Neck angular displacement and velocity measured

*This table represents a continuation of the 18 studies summarized in the first quarterly report.

1972, pp. 58-83. Although only limited, in that only two of 55 victims of automobile accident cervical spine injuries involved "forceful extension of the head and neck following a rear-end collision (whiplash)" the resulting mechanical analysis appears to be a distinct contribution to the literature. Dr. Portnoy is our neurosurgeon consultant, and Dr. Melvin our biomaterials engineering consultant on this study.

2. Subject Pool

The subject pool selection criteria, together with an illustration of the subject's health questionnaire, and subject consent form have previously been detailed in the first quarterly report. Subjects to date have come from the 18 through 24 year old age group, primarily because they are easiest to obtain and often more flexible concerning scheduling. In addition, the first subjects require more time than it is anticipated that subsequent subjects will, until measurement techniques and procedures are refined most efficiently and measurers become more proficient. Further, the younger age group is more adaptable to the requirements of the preliminary tests.

At this time a total of 17 subjects have been utilized in either preliminary experimental tests of techniques and/or equipment or in initial radiography and anthropometry. All but 10 subjects required for the total 18-24 age subject pool have been recruited. However, since these 50 subjects are primarily from the student population, we can anticipate losing some due to vacation mobility, summer jobs, or other related activities decreasing their availability. Nevertheless, we do not anticipate any problems in continuing to obtain adequate numbers of subjects in this age range. In a few cases, additional subjects may have to be included to replace those who have completed the preliminary measurements, but have disappeared prior to completion of all tests.

The subject protocol has been modified slightly. The procedure now involves three steps:

(1) The potential subject volunteer completes the medical questionnaire. It is then screened by Dr. Baum or Dr. Threatt, our radiologist consultants.

(2) If the subject passes this initial medical screening, he is then contacted for the first series of tests. These consist of five x-rays, at least 12 photometric exposures, and anthropometry measurements. At this time the subject also signs the consent form. The x-ray films are reviewed by Dr. Baum or Dr. Threatt prior to continuing with the balance of the tests. It is important that both the radiography and photometric exposures be taken at the same session with the subject wearing the headpiece in the same position so that the marker reference points are identical for each measure.

(3) If the x-rays indicate no medical problems involving risk, and the medical questionnaire indicates no adverse history, the subject is then called in for the remaining strength and range of motion tests. Anthropometry may be optionally conducted at stage two or three.

It is anticipated that subject measurement will considerably increase now that the equipment, techniques, and instrumentation have been standardized.

3. Anthropometry

Subject anthropometric measurements have now been taken on 17 subjects, although this includes subjects used in preliminary testing, some of whom may be excluded from the study population. Both the subject selection criteria and specific descriptions of measurements have been previously detailed in the first quarterly report and will not be repeated at this time. This includes 3 standing measures, 32 seated measurements, and 8 measurements required to determine body physique.

In addition eight other measurements have been listed as desired in order to provide information which might have useful application or to provide an additional basis for comparison with other populations. These include seated hip breadth, seat height of right anterior iliac spine, seat surface to trochanterion (vertical, seated), seat back to trochanterion (horizontal, seated), sitting-knee height, sitting-knee clearance, buttock-knee length, and chin-neck intersect. While these are not considered important to the basic study of the neck, each would help to define and relate characteristics of our population to the seated environment. Due to difficulties in obtaining some of these measurements on the clothed subject, we will continue to list these as optional and obtain where possible.

An anthropometry form has been designed as shown in Table II. One addition will be notation of the time of day the measurements were taken. The anthropometry is taken either when the subject is x-rayed or when the final strength, range of motion, and muscle reaction measurements are taken.

TABLE II. SUBJECT ANTHROPOMETRY FORM.

SUBJECT NUMBER ____________________ DATE ____________

TIME OF DAY ____________

A. STANDING (ERECT)

1. Weight
2. Stature
3. Cervicale (C7)

B. SEATED

1. Sitting Height (slumped)
2. Sitting Eye Height (slumped)

SEATED (ERECT)

3. Sitting Height
4. Sitting Eye Height
5. Sitting Cervicale Height
6. Sitting Suprasternale Height
7. Nasal Root Depression
8. Right Tragion
9. Left Tragion
10. Sitting Right Shoulder (acromion) Height
11. Sitting Left Shoulder (acromion) Height
12. Biacromial Breadth
13. Shoulder Breadth (Bideltoid)
14. Anterior Neck Length
15. Posterior Neck Length
16. Lateral Neck Breadth (Mid)
17. Anterior-Posterior Neck Breadth (Mid)

SEATED (RELAXED)

18. Superior Neck Circumference

19. Inferior Neck Circumference ______

20. Head Circumference ______

21. Head Ellipse Circumference (Bennett) ______

22. Head Breadth ______

23. Head Length ______

24. Head Height ______

25. Sagittal Arc ______

26. Coronal Arc ______

27. Bitragion Diameter ______

28. Minimum Frontal Diameter ______

29. Minimum Frontal Arc ______

30. Bitragion Minimum Frontal Arc ______

31. Bitragion Inion Arc ______

32. Posterior Arc ______

C. SKINFOLD (FAT) MEASURES

1. Biceps Flexed Circumference (Right) ______

2. Calf Circumference (Right) ______

3. Femoral Biepicondylar Diameter (Right) ______

4. Humerus Biepicondylar Diameter (Right) ______

5. Right Triceps Skinfold ______

6. Right Subscapular Skinfold ______

7. Right Suprailiac Skinfold ______

8. Right Posterior Mid-Calf ______

Several equipment modifications have occurred since the last report. Figure 1 shows the anthropometry area of the Cervical Measurements Laboratory. Primary instruments are the anthropometer, scales, sliding and hinged calipers, measuring tape, and skinfold calipers. A special seat has been designed and constructed, shown in Figure 2, which allows seated measurements to be taken more efficiently and accurately. This has no seat back, since the majority of measures are head and neck. The anthropometer has been modified with a wooden block at the base to assure vertical alignment from the seat base or floor, since this is difficult to do without an assistant, and will increase accuracy of measurement. A second anthropometer has been mounted to the wall to obtain stature faster and more accurately. Both the scale (weight) and skin caliper have been calibrated, and will be continuously checked for error. All anthropometry continues to be done by a single individual to further reduce error.

4. Radiography

To date 17 subjects have had a complete set of five x-ray films taken; however, not all of these will be used in the study population since several involved preliminary tests. Radiography is used both to screen the subjects for possible medical defects that might make further tests hazardous to the subject, and to obtain basic structural configurations in the neutral seated position, and with the neck hyperextended and hyperflexed. Presently four lateral views are taken on 10 x 12 inch film size and one in the anterior-posterior seated position on 8 x 10 inch film. One view involves a lateral seated position on a hard seat which duplicates the seat used in the Cervical Measurements Laboratory, and a second lateral x-ray is taken with the

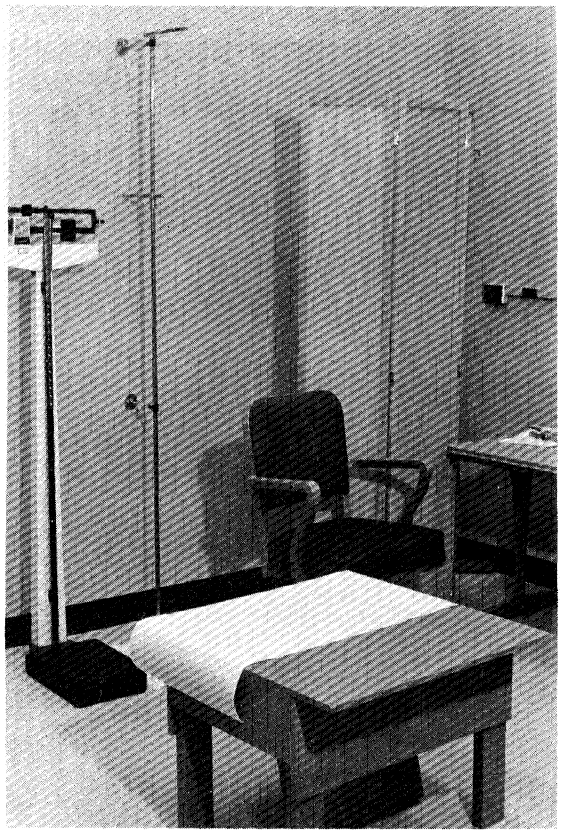


Figure 1. Anthropometry Area of Cervical Measurements Laboratory, Showing Scales, Anthropometer, Anthropometry Chair and Dressing Screen.

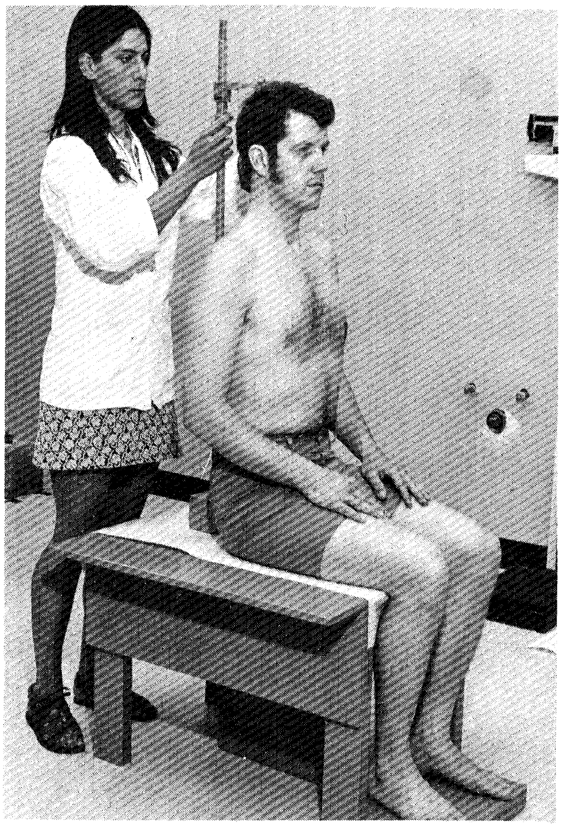


Figure 2. Subject Seated on Anthropometry Chair. Erect Sitting Height Measurement Being Taken with Anthropometer.

subject seated in a 1972 Pinto bucket seat, modified to duplicate the seat pan and back angle (103°) of the rigid seat.

To date, little difference has been found in the configuration of the vertebral column between soft seat and hard seat x-rays. After more subjects are x-rayed, a statistical test will be conducted to determine if significant differences do in fact exist. If not, it may be possible to eliminate the soft seat x-ray.

In the previous quarterly report, we reported having some difficulty consistently identifying landmarks in the x-rays. This was because the mobility of the head in extension and flexion, especially for tall subjects, would often result in the markers falling outside the film size. The problem has now been solved without the necessity of increasing film size or radiation exposures. A photogrammetry headpiece has been constructed and is now in use. The headpiece (illustrated in Figure 3) has built-in adjustable nasion and tragion lead markers and a metal indicator rod which is positioned on a line between nasion and tragion. This line is used as the reference from which head angles are measured and it appears in every view. In addition, markers at C-5, C-7 and suprasternale are exposed in each view, as is a small plum bob which provides a vertical reference and a magnification factor. The x-rays are now able to serve the dual purpose for which they were intended--medical screening and accurate size and angular measurements of internal structures.

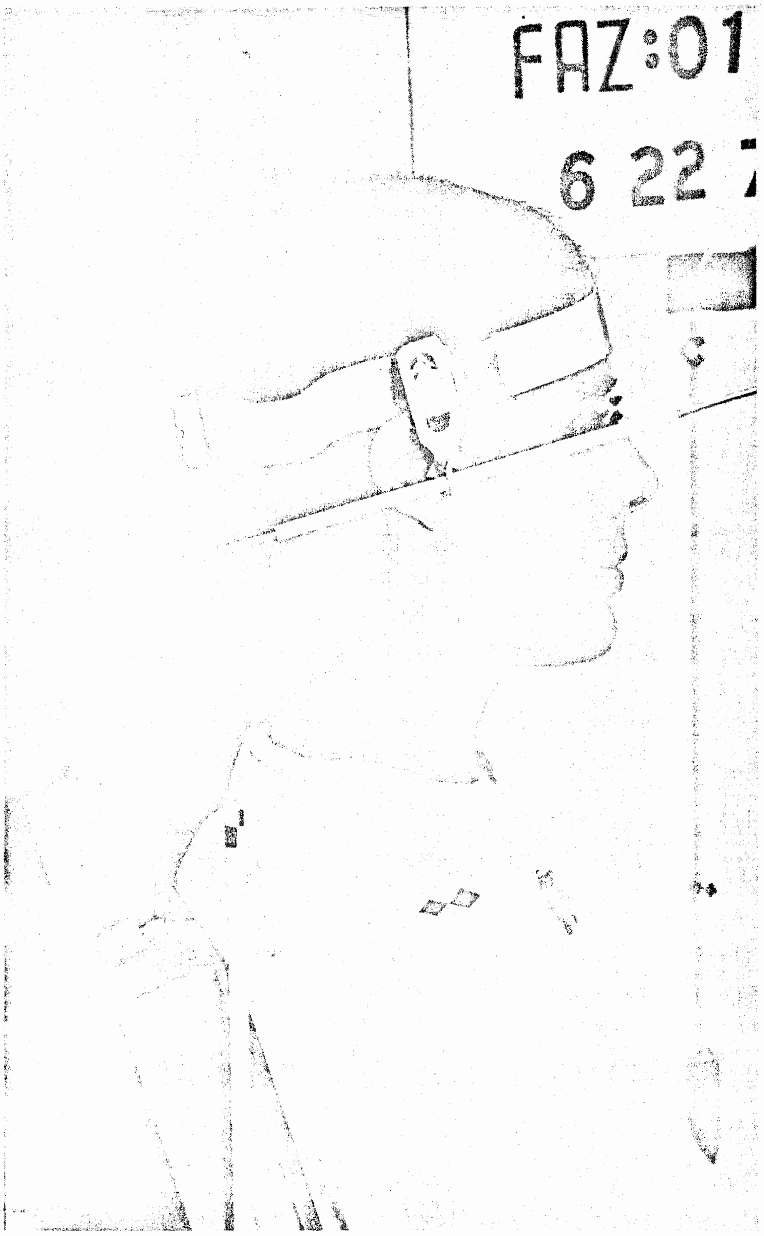


Figure 3. Subject Wearing Photogrammetry Headpiece. This Headpiece is Worn when X-rays and Photogrammetric Photographs are being Taken. Lead Markers and Bullseyes Attached to the Headpiece Mark Nasion and Tragion; the Straight Rod Indicates the Line Between Nasion and Tragion.

5. Reaction Time Measurements

Cervical muscle reaction time is defined for this study as the time difference between the start of acceleration of the head (after a weight is dropped to create an impulse load) and the start of significantly increased activity in the muscle EMG. All of the apparatus necessary to measure reaction time parameters has now been assembled and checked out with four subjects. The apparatus consists of a triggering mechanism with an electromagnet to release the weight, small surface electrodes to detect muscle activity and a headpiece.

The headpiece used in reaction time measurements is shown in Figures 4 and 5. The headband is a modified welder's helmet headband, adjustable for head circumferences of 21-25 inches. To transmit the force of the released weight to the head a yoke arrangement was devised. The arms of the yoke are attached to studs on the headband at approximately the plane of the center of gravity of the head. A semiflexible linkage and cable arrangement with a small pulley allows the loading force to be directed straight back (or forward) even if the subject's head is slightly tilted or rotated. Also, with the load being applied at points on the side of the head, the yoke arms can be positioned in front or back of the subject without removing the headpiece. Instantaneous head accelerations are detected and measured by two B & K type 4333 accelerometers mounted in the plane of load application ("linear" acceleration) and 90 degrees to it ("angular" acceleration). A thermoplastic material was used for the three arms that attach the accelerometers to the headband. Also, to reduce signal losses from the low levels of acceleration being detected, a preamplifier for each accelerometer was mounted on the headpiece. The entire headpiece with yoke,

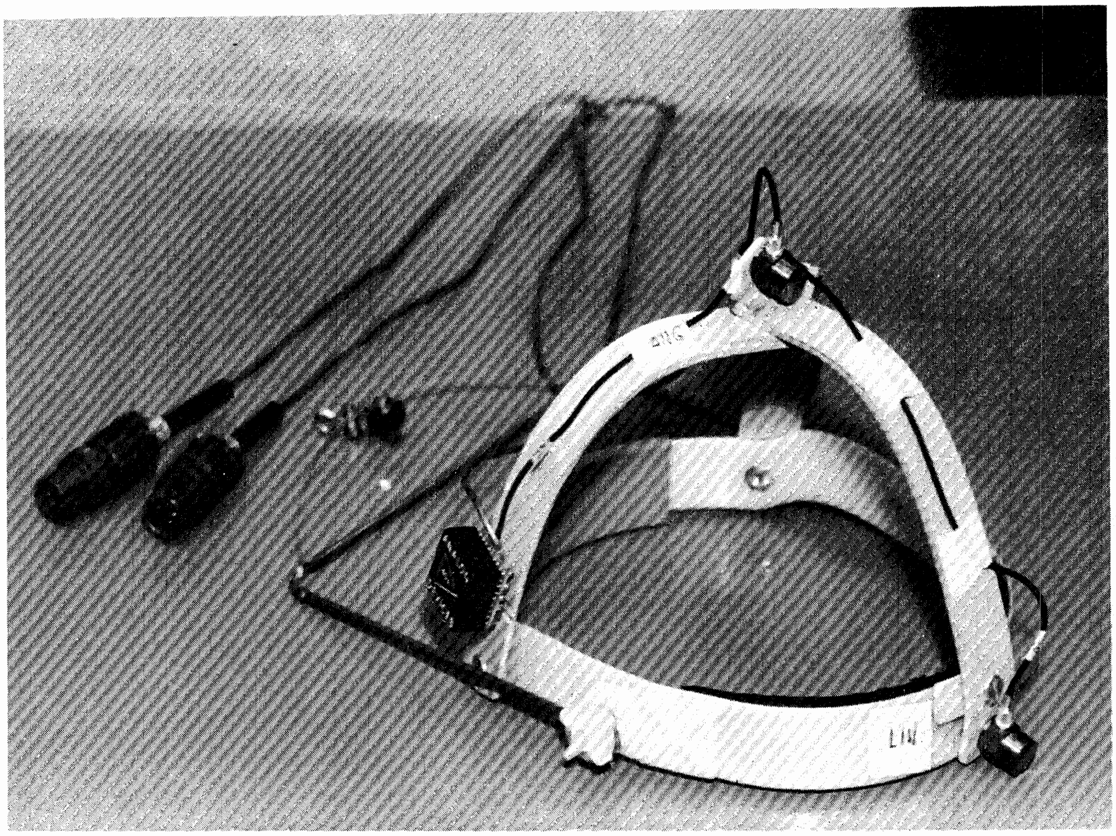


Figure 4. Headpiece Used for Reaction Time Measurements. Accelerometers at Top and Front Detect Head Accelerations; Light Weight Preamplifiers on Headpiece Reduce Acceleration Signal Loses. Yoke Arrangement Transfers Loading Forces to Area of Head C.G.

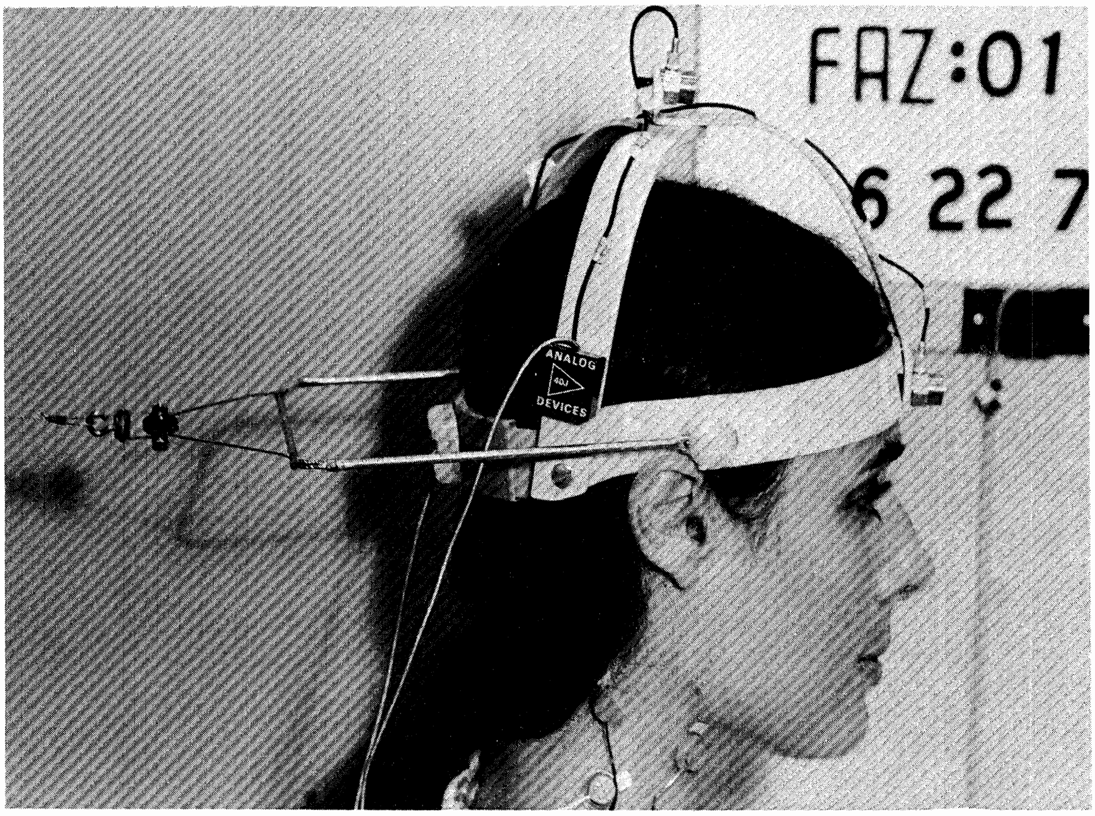


Figure 5. Closeup of Subject Wearing Headpiece Used in Reaction Time Measurements. Note Surface Electrodes Used to Measure EMG from Neck Flexor and Extensor Muscles.

accelerometers, and preamplifiers is very lightweight, weighing only 280 grams, approximately 6/10's of a pound.

Figure 5 illustrates the headpiece position for a test of neck flexor reaction time. The cable at the left is passed over a pulley wheel and attached to the weight. This figure also shows the relative positions of the EMG electrodes. Two are placed on neck flexors (only one of these is shown), two on neck extensors, and one ground electrode over a bony area.

The general laboratory arrangements for reaction time tests are shown in Figures 6 and 7. Figure 6 is a simulation of an extension test, just after the weight has been released. The dropping weight has extended the subject's head slightly (1-2 inches), and signals have been recorded from neck flexors (EMG), neck extensors (EMG), the two accelerometers, and a displacement transducer (a potentiometer attached to the hub of the pulley on the triggering mechanism). When the investigator releases the microswitch, the electromagnet is again activated and the lab assistant can replace the weight, relieving the load.

After three trials have been recorded in extension, the triggering mechanism is relocated to the front of the test fixture, the headpiece yoke is repositioned and three trials are recorded with the weight imparting a flexion load to the subject (Figure 7).

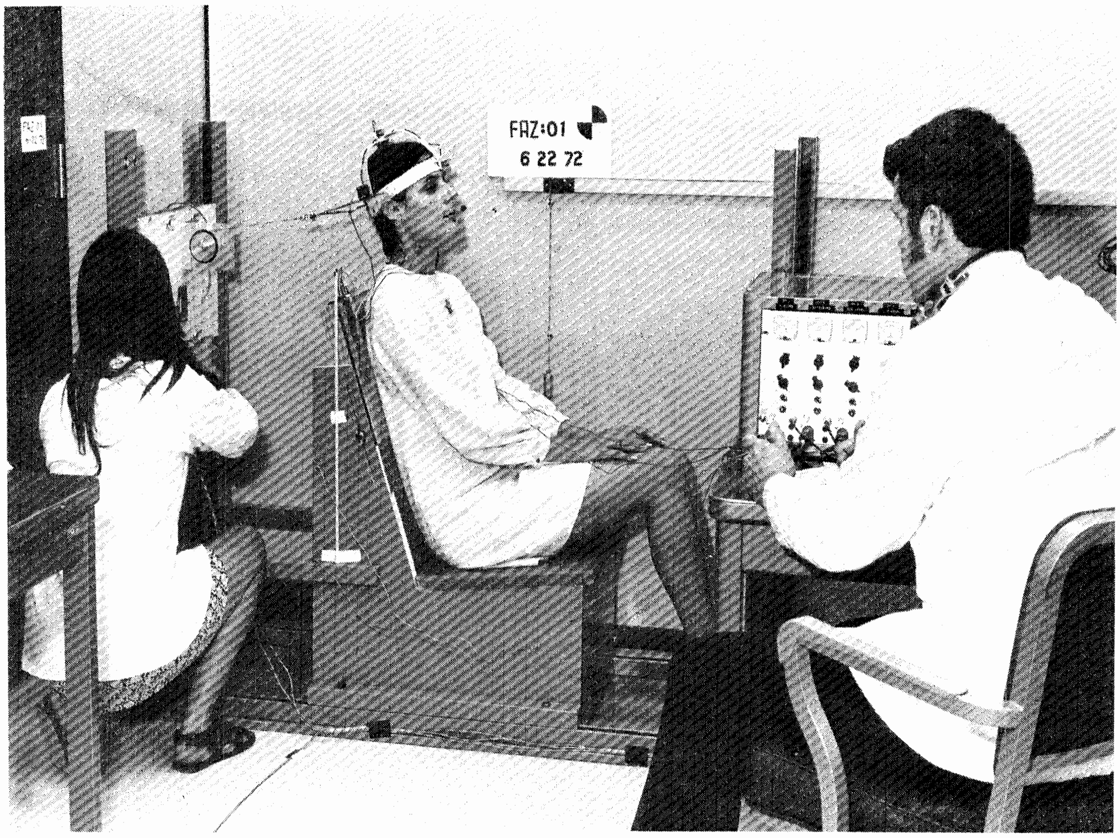


Figure ~~12~~ 6. Simulation of Test for Reaction Time in Extension. Weight was Released when Investigator (right) Presses Microswitch Trigger. Note Subject's Head Tilted Back Slightly. This is Approximately the Maximum Head Motion Observed to Date.

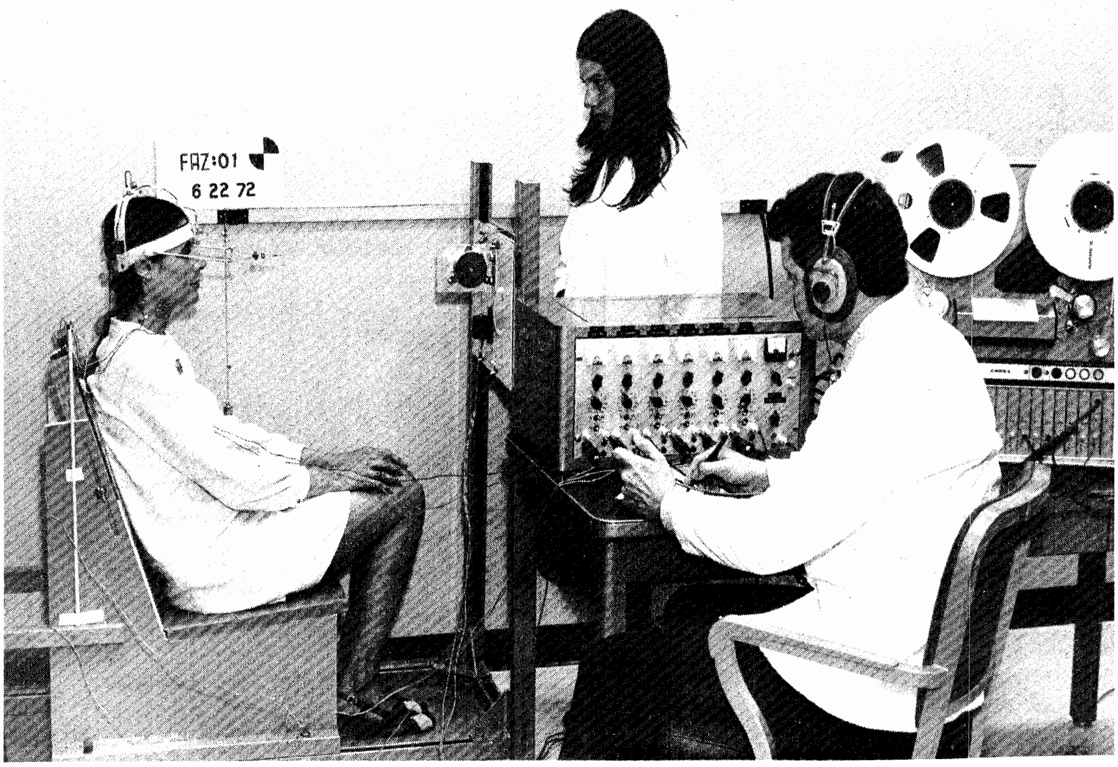


Figure ~~13~~ 7. Subject Prepared for Test for Reaction Time in Flexion. Triggering Mechanism has been Relocated in Front of Subject.

6. Strength Measurements

The strength of neck flexors and extensors is measured using a different apparatus from that used in reaction time measures. Figure 8 shows the arrangement used to measure neck flexor strength. The subject wears a cloth headband, 1-3/4 inches wide, made of nonstretching nylon webbing. The headband is attached to a force ring with a 3/8 inch diameter woven nylon cord (also inelastic). The force ring has four strain gages mounted on it which are wired into a bridge circuit. The bridge imbalance as the subject pulls against the force ring is proportional to muscle strength. The EMG electrodes remain attached and EMGs are recorded during this portion of the testing procedure. Neck flexor strength is measured in three trials, each trial being a maximum exertion sustained for four seconds. Neck extensor strength is measured in a similar manner, but with the force ring positioned in front of the subject, as in Figure 9.

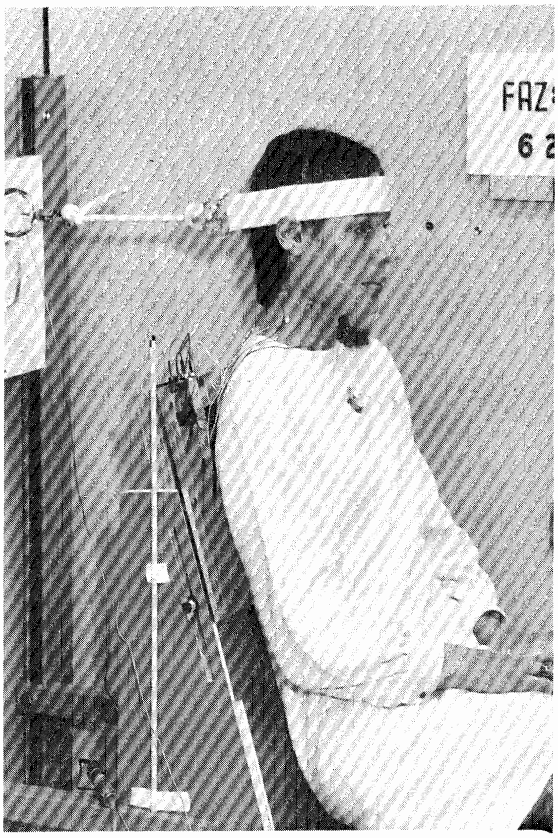


Figure 8 . Subject Positioned for Strength Test of Neck Flexors. Note Wide Headband and Force Ring with Strain Cages.

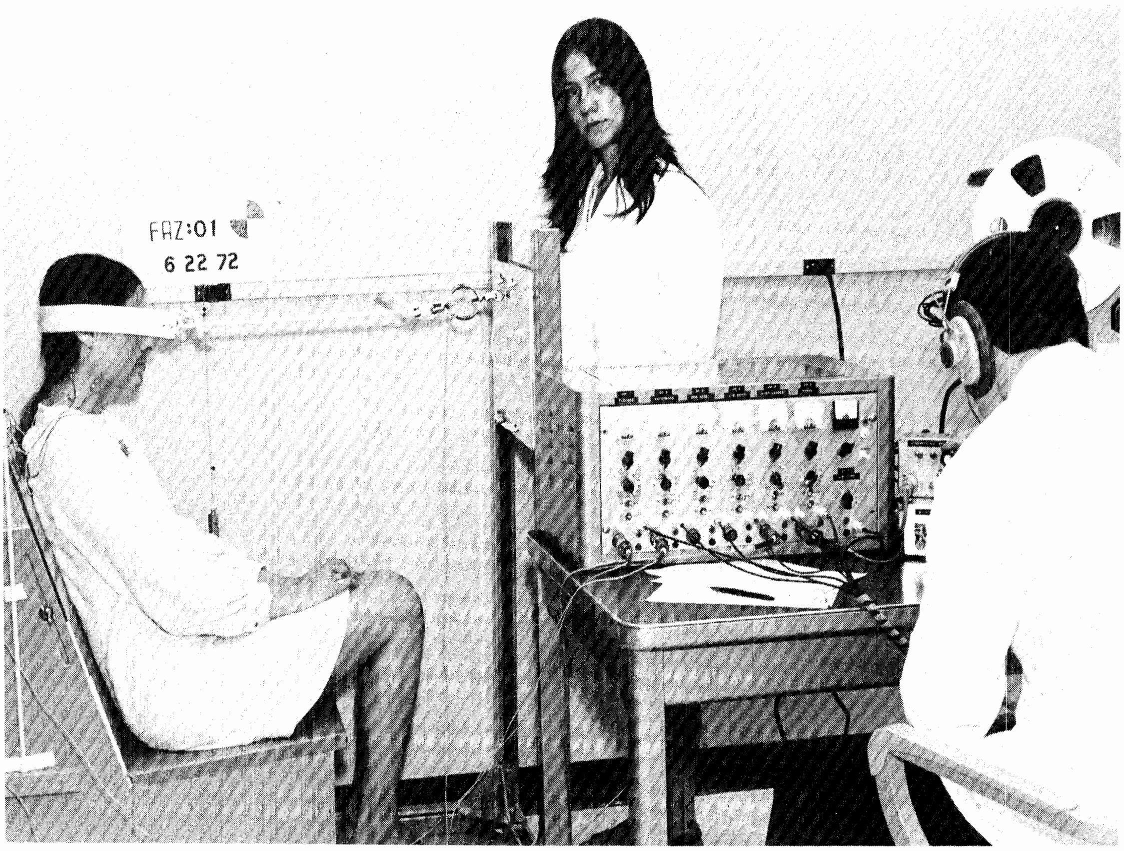


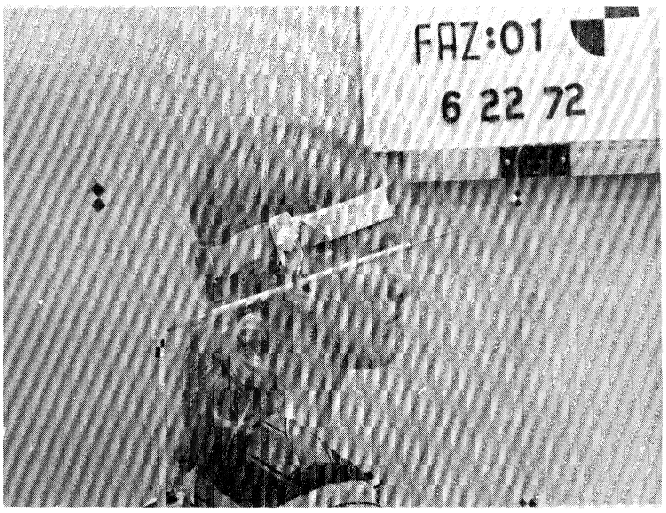
Figure 9. Subject Positioned to Measure Strength of Neck Extensor Muscles.

7. Photogrammetry

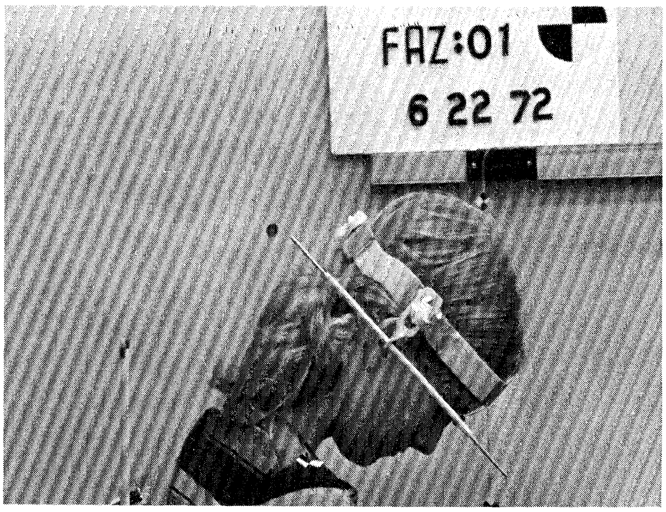
Two 35-mm cameras are being used to take photographs for photometric analysis. One camera is positioned laterally to the subject and the other in front of the subject. Solenoid controlled automatic shutter releases have been installed to trigger the shutters of both cameras simultaneously.

Immediately after taking the x-rays, the subject is brought to the Cervical Measurements Laboratory and is placed in the hard seat. The photogrammetry headpiece (Figure 3) remains in the same position as it was for the x-rays. Light-reflective bullseye markers are placed on the nasion and tragion markers on the headpiece, and also at the suprasternale and acromion locations. The subject is asked to duplicate the neutral, flexed and extended positions just achieved for the x-rays. Exposures taken by the lateral photogrammetry camera are shown in Figure 10 for subject FAZ01. Measurements of head angles in the various positions can be directly compared with similar measurements from x-rays since the headpiece location is not altered and the chair configurations are identical. During the next quarter, a repeatability assessment will be conducted. The subject will be asked to repeat each position three times during the photogrammetry session. A statisical comparison will be conducted to determine how closely the same person can repeat the neutral and voluntary extreme positions.

The graph-check camera mentioned in the previous report was not purchased. Stop action photography during reaction time tests is now thought to be of doubtful value because of the slight head movements being observed. Should stop-action be desired in the future, a stroboscopic light is available which could be used in conjunction with a 35-mm time exposure to provide the desired record.



10a. Subject in Neutral Position for Photogrammetry Measurement. Note Photogrammetry Origin on Rod Behind Subject and Verticality Markers in Front of Subject.



10b. Subject in Flexed Position.

10c. Subject in Maximum Voluntary Extension.

Figure 10. Three Views to be Analyzed Photogrammetrically. These Views are Intended to Duplicate X-ray Views.

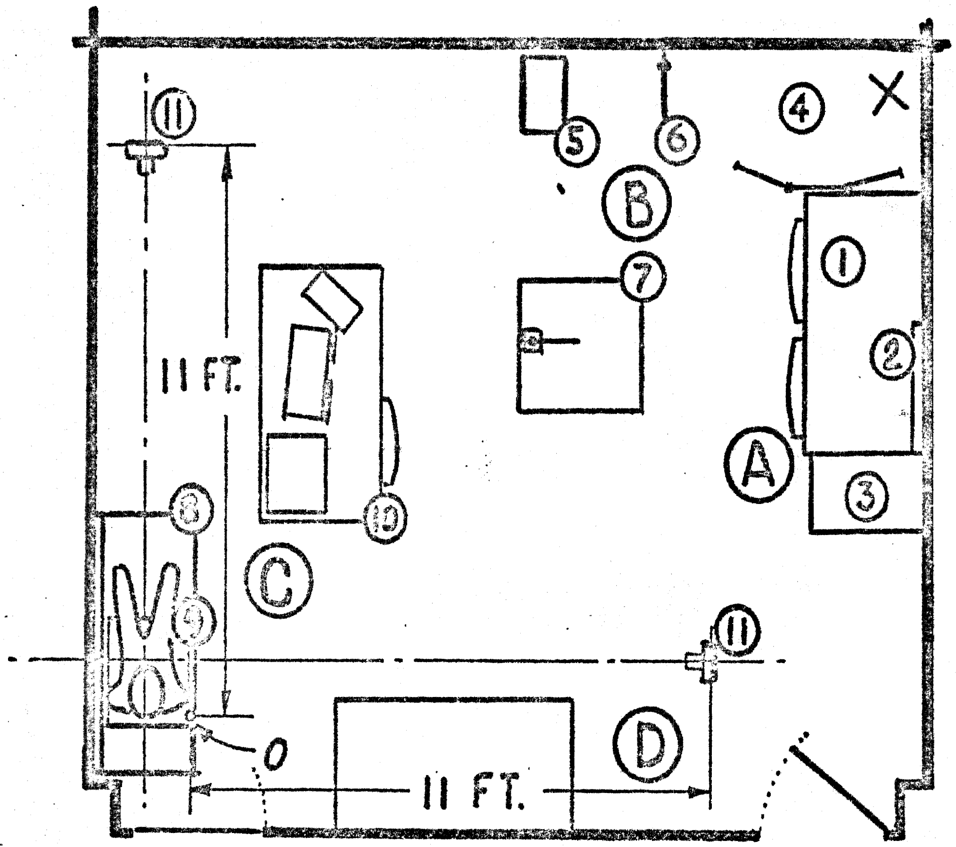
8. Cervical Measurements Laboratory Test Protocol

With the availability of the electronic equipment and the experience of testing four subjects, it has been possible to develop more standardized and refined test procedures than those reported last quarter.

Early observations demonstrated that a rear view of the subject would be inadequate for photogrammetry, and a front view was adopted. This necessitated a rearrangement of the equipment in the Cervical Measurements Laboratory, and the test fixture was placed so the subject faces a 35-mm camera. The current laboratory configuration is shown in Table III. Note that the photogrammetry "origin" has now been established and that the film plane of each camera has been positioned a known fixed distance from this origin.

The electronic equipment being used in the testing procedure is grouped together, as shown in Figure 11. A seven-channel amplifier and monitor has been built especially for this study. Each channel of data can be monitored on the VU meter associated with it, or the signal can be displayed on the oscilloscope or strip-chart recorder by selecting the proper channel from the monitoring circuit in the upper right hand corner of the unit. The bridge circuitry and calibration electronics for the muscle strength transducer is shown in the center of Figure 11. Directly beneath it is the 24-volt dc power supply for the electromagnet trigger and camera shutter-release solenoids. The Ampex Model PR500 7-channel recorder-reproducer is configured for 1/2-inch magnetic tape and has been checked out and calibrated on-site by the local Ampex service representative. The oscilloscope and strip-chart recorders are used for monitoring only and are not an integral part of the data-gathering procedures. These last two pieces of equipment are on loan from other

TABLE III. CURRENT PHYSICAL LAYOUT OF CERVICAL MEASUREMENTS LABORATORY SHOWING REVISED ORGANIZATION



A. Briefing and Record-keeping Area
   1. Table--subject briefings
   2. X-ray viewer
   3. File cabinet

B. Anthropometry Area
   4. Dressing area--clothes rack, screen
   5. Scales
   6. Anthropometer
   7. Hard chair for anthropometric measurements

C. Active Measurements Area (Range of Motion, Muscle Reaction Time, Neck Strength)
   8. Test fixture, measurement device supports
   9. Hard chair and subject
   10. Equipment table--amplifier box, tape and strip chart recorders, oscilloscope

D. 11. 35mm cameras--photogrammetry
   (0 is origin for photogrammetric analysis)

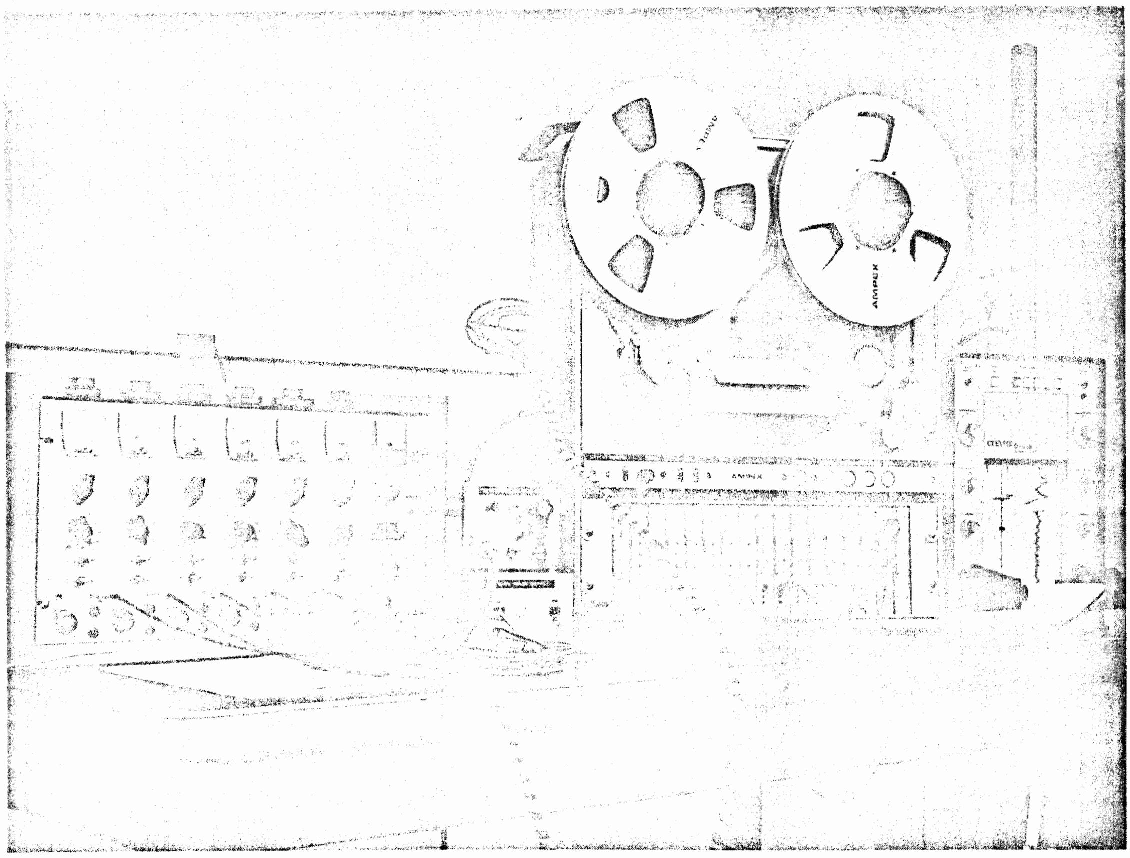


Figure 11. Electronic Equipment in Cervical Measurements Laboratory. Shown Left to Right, is 7-Channel Amplifier/Monitor, Muscle Strength Calibrator, 24v-dc Power Supply, Ampex PR500 7-Channel Tape Recorder, and Brush Strip-Chart Recorder. The Oscilloscope is not Pictured.

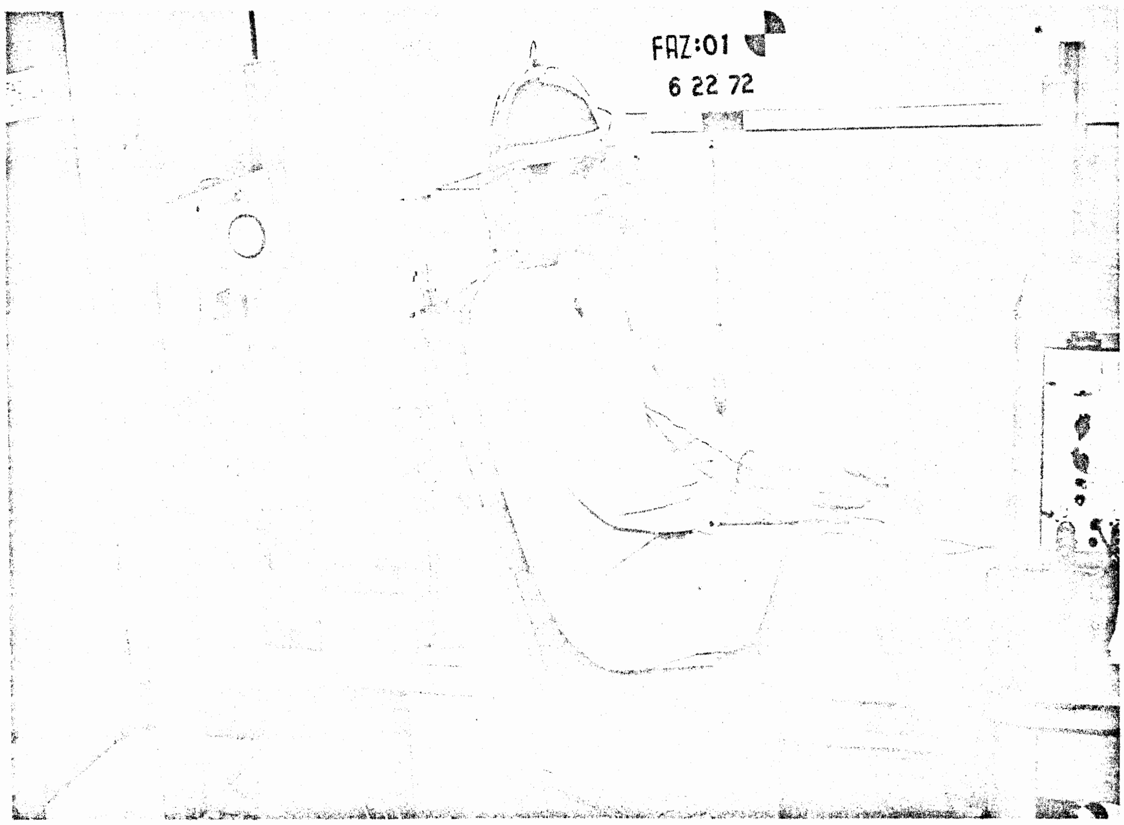


Figure 12. Subject Seated in Test Fixture Hard Chair. Headpiece and Triggering Mechanism Attached, Ready for Extension Test of Reaction Time.

laboratories and have not been purchased with project funds.

Figure 12 is a general view of a test subject in the test fixture. The chair is used for photogrammetry, reaction time and strength procedures, as described previously. The equipment has been constructed with insulating materials in critical places to prevent the possibility of establishing potentially hazardous ground loops.

A revised test protocol has been established. A summary of the current procedures is as follows:

1. The subject receives a thorough briefing on the test procedures involved, including a description of the objectives of the test. This is intended to motivate the subject to relax when necessary and to exert a maximum voluntary effort when necessary. The subject is asked to repeat his understanding of the procedures in accordance with Human Use Committee requirements.
2. Anthropometry is taken if these measurements have not been taken at the same time as the subject was x-rayed.
3. The electronic equipment is calibrated, EMG electrodes are attached to the subject, and the subject is seated in the test fixture. The reaction time headpiece is then fitted.
4. EMG, acceleration and displacement channels are checked for proper operation. Amplification levels are set and noted on tape.
5. The triggering mechanism is placed behind the subject for the measures of reaction time in extension. The weight is attached to the headpiece. The subject is asked to tense his neck muscles and the weight is released so that the subject can feel how little effort is required to restrain the weight. This convinces the subject that the test is not harmful and assists in achieving a relaxed state for the actual tests. The subject is then asked to

completely relax his neck muscles (an oscilloscppe placed in front of the subject allows him to monitor his own EMG activity and concentrate on relaxing the muscles). At least three trials are recorded. Then the triggering mechanism is moved to the front to the test fixture and the test is repeated for reaction time in flexion.

6. The reaction time headpiece is removed and the strength measurement apparatus is positioned, first behind the subject to measure flexor muscle strength. When the subject is ready, a strength calibration is conducted. The calibration is set for 10 pounds and the subject is asked to pull against the force ring. The tape is marked when 10 pounds has been achieved. The calibration is repeated for 20 pounds and, if the subject appears to be very strong, for 30 pounds. The calibrator is then set for 30 pounds (40 for strong subjects) and the subject is asked to exert a maximum voluntary pull without changing body configuration. Two EMG channels and the strength channel are recorded. The exertion is held for 4 seconds. Three trials are run,each of four seconds duration, each with 30 seconds of rest between trials. The apparatus is then positioned in front of the subject and the calibration steps and three maximum exertions are repeated for the neck extensor muscles.

7. When the tests are completed, the headpiece and electrodes are removed from the subject, after which he is asked his reaction to the tests. Finally, he is thanked for his participation, paid, and excused.

9. Initial Data Analysis

Four subjects (3 females and 1 male in the young age group, but including short, middle and tall stature groups) have been evaluated by the preceding test procedures. This was instigated primarily to evaluate the equipment and procedures prior to the large-scale testing program. For example, the sensitivity of the measurement techniques to the basic physiological processes had to be established, as well as the repeatability of the specific measures.

The analysis of the acceleration, mobility, and electromyographic data thus far obtained has been accomplished through strip-chart records from the magnetic tape recordings, as opposed to computer analysis. This is deemed necessary until the final recording technique is standardized. It is expected that within the next month such a set procedure will be established, after which computer algorithms will then be developed. Thus by the end of the next report period automated data analysis should be demonstrable.

It should be noted that the four subjects tested thus far will be recalled for repeated measures utilizing the automated, standardized test and analysis procedures. The results of the present analyses are described in the following subsections.

Radiography and Photogrammetry for Neck/Head Alignments. One major procedural question was to determine how photogrammetry measures of the range of motion of the neck and head complex would compare with x-ray measures. To develop some comparative data the four subjects were first fitted with a headpiece which could be adjusted to line-up a metal rod (alignment reference axis) to be parallel to a line bisecting the right tragion and nasal root depression reference points, (see Figure 13).

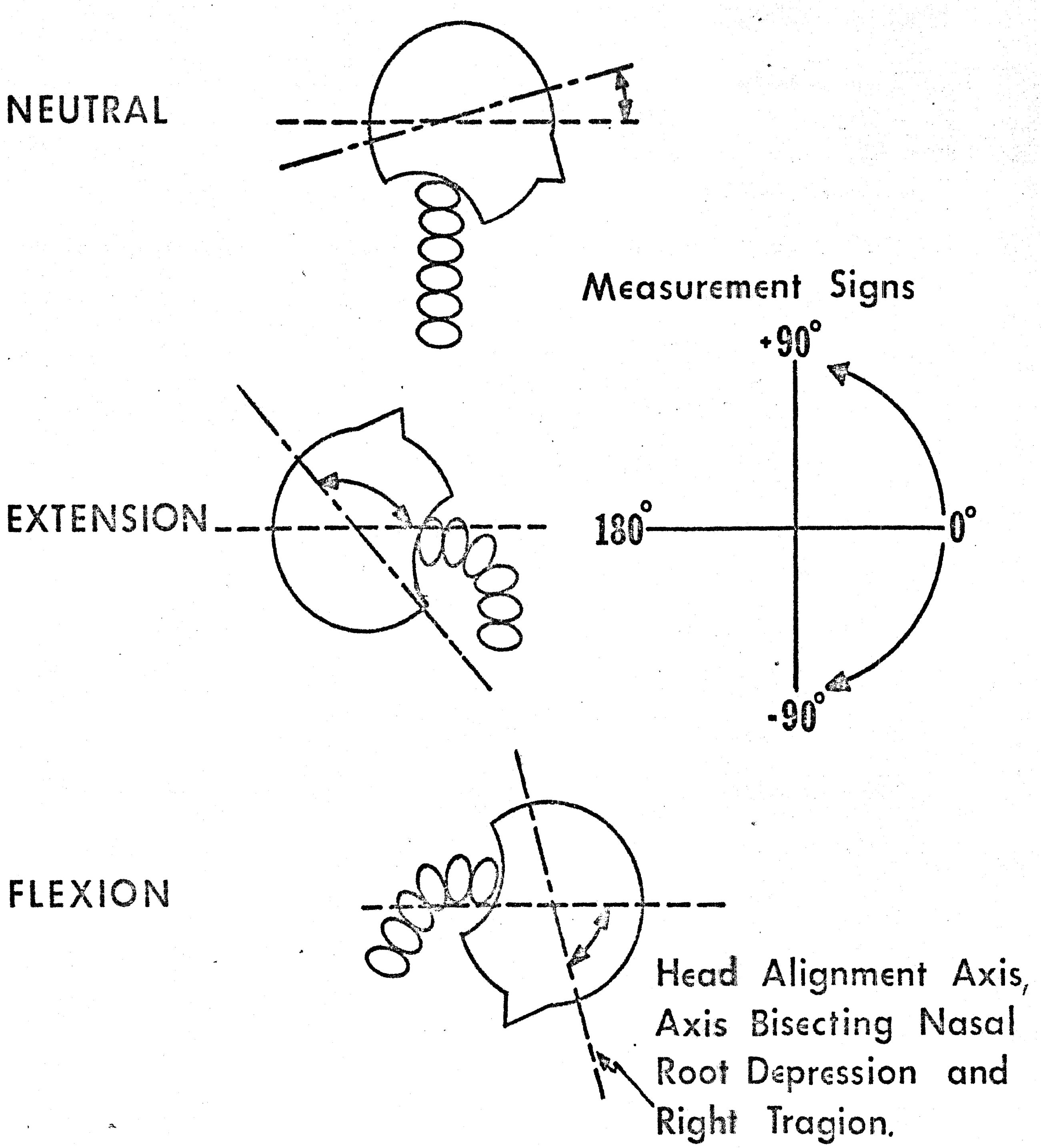


Figure 13. Illustration of Head Alignment Measurement Technique

The subjects then assumed the three requested positions (e.g. neutral, flexed, and extended), while both the x-rays and later photographs were taken.

Comparison data from both techniques is described in Table IV, and is graphically presented in Figure 14. Though only four subjects were involved it is believed that a bias is not present between the two techniques. More data will be gathered in the next quarter to allow a stronger statistical statement on this question. This comparative data will better allow the prediction of head/neck mobility, inasmuch as the photogrammetry provides the means for repeated measures of mobility of many people. The comparative data would be used to translate the photogrammetric mobility data to the more limited x-ray mobility data of the entire cervical neck.

A separate but similar question is in regards to the effects of the soft seat and hard seat on head/neck mobility. The comparative data was developed from x-rays of the head alignment reference axis (Table IV) chosen when in the neutral positions in both the hard and soft seats. It is not clear yet whether a specific bias is introduced when sitting in either type of seat. The data of next quarter should clarify this issue.

It should also be noted that the x-rays have been of sufficient quality to well define the cervical vertebrae. Thus, no measurement problems are anticipated in the dimensional evaluation of cervical mobility of the population. In general, both the x-ray and photogrammetric procedures appear to be operational, and measurement repeatability will be ascertained in the next quarter.

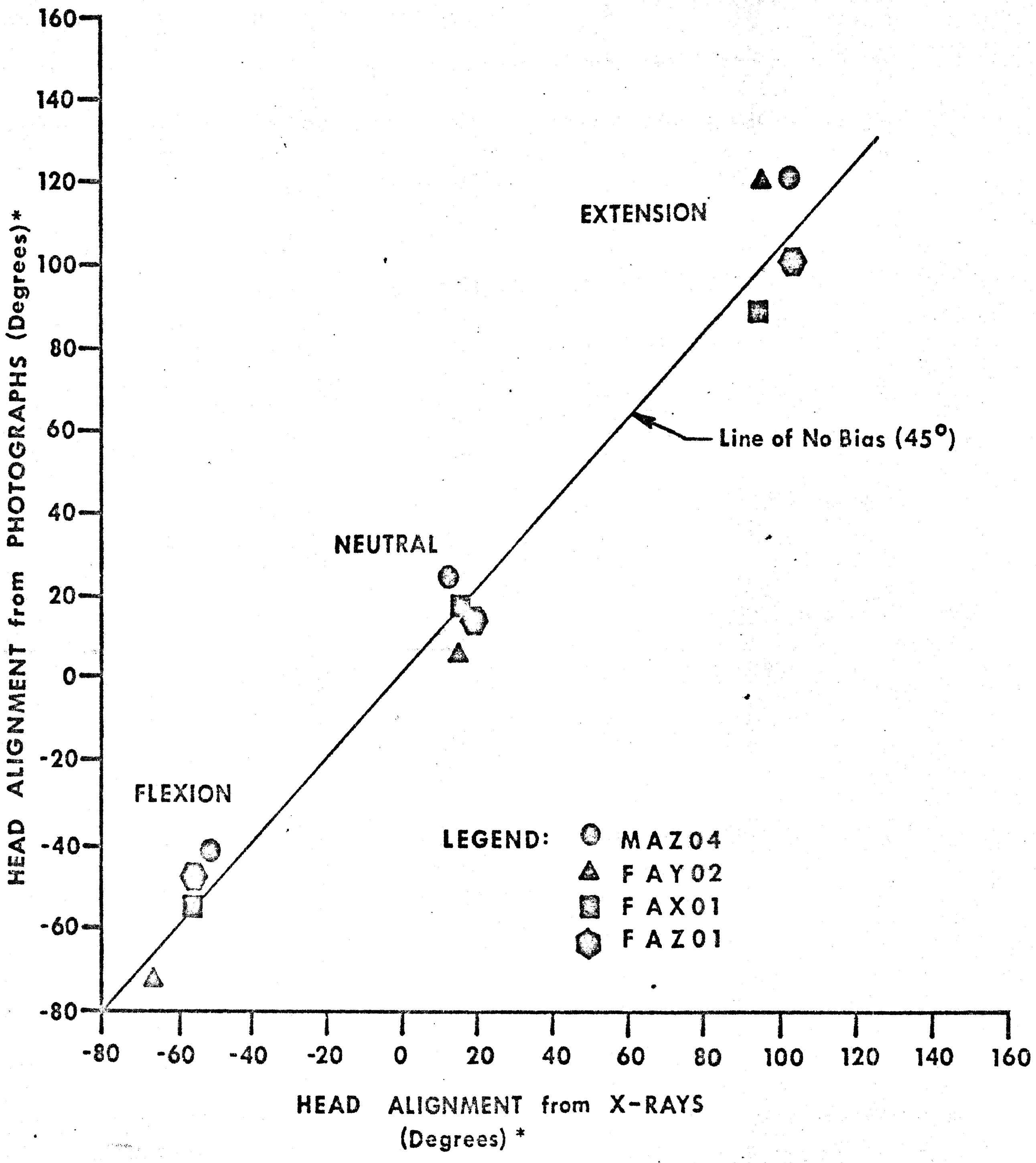
Cervical Neuromuscular Reaction Time. Data have been obtained on three of the subjects relating to the latency between the start of acceleration

TABLE IV.

COMPARATIVE HEAD ALIGNMENT ANGLES

	Photographic Data			X-ray Data			
Subjects	Neutral	Extended	Flexed	Neutral	Extended	Flexed	Neutral Soft Seat
MAZ04	24.5	122.2	-41.0	10.7	101.2	-53.0	13.0
FAY02	8.8	80.7	-72.4	13.8	94.8	-67.2	15.3
FAX01	16.8	90.0	-54.0	14.5	93.6	-56.5	16.2
FAZ01	15.1	103.5	-48.6	18.4	102.8	-55.0	11.4

Data from photographs and x-rays.Angles are degrees in relation to horizontal axis, as defined in Figure 13.



*Angles defined in Figure 13.

Figure 14. Comparison Data of Photographic and X-ray Neck/Head Mobility.

of the head and an increase in EMG amplitude following impulse loading of the head. The measurement concept is described in Figure 15. The measure used for this report is the raw EMG (center) rather than the integrated (bottom). With automated analysis a set of criteria will be developed based on a forgetting type digital integration program to ascertain when significant muscle response begins.

The data from the present study is summarized in Table V for both flexion and extension actions. What is clear in this initial data is that high variability is present. Until more subjects and the digital programs are established, however, it is not clear as to whether this is due to the analysis procedure or to actual subject variability.

Some problems have been encountered in this test. Primarily, the subjects have been contracting prior to the weight dropping, thus causing a high-activity EMG when "resting." In addition, anticipatory responses "stiffen" the neck and thus dampen the acceleration. This then eliminates the stretch reflex. Partially this problem is due to the instructions given the subject which requires the subject to "relax but maintain a slight tension on the cable attached to the head fixture." It is believed that this "preload" is not necessary if a controlled amount of slack can be developed in the cable. A procedure to obtain this is being worked out, and will be tested in July prior to testing many additional subjects. Also, by using a controlled cable slack the impulse loading can be varied to give the anticipated one G acceleration. At present the average peak head acceleration appears to be between 0.2 and 0.3 G's which is not sufficient to give a good stretch reflex. If one G is still not obtained, additional weight may be added. If additional weight is utilized in the procedure, it will be cleared with the

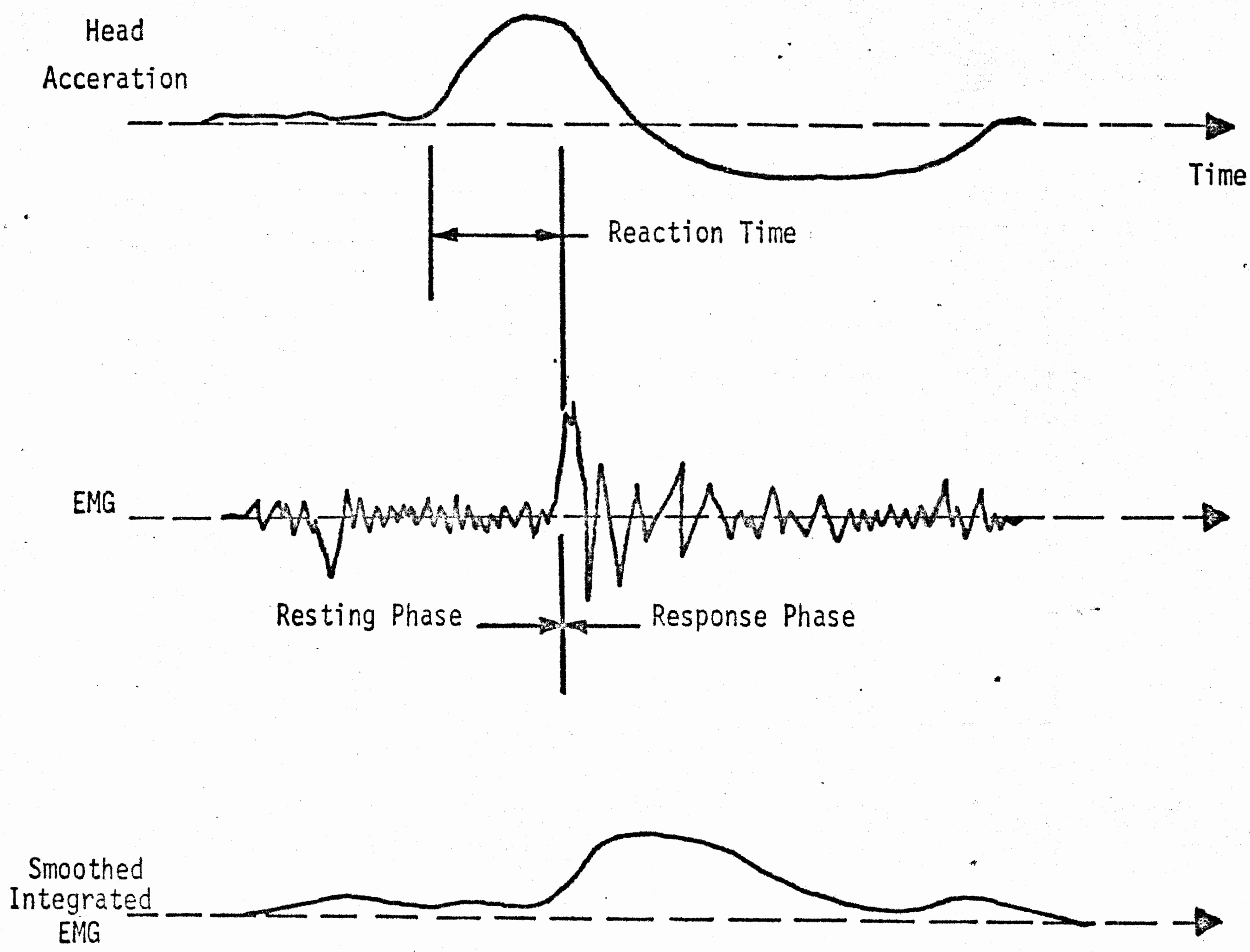


Figure 15. Illustration of Reaction Time Measures of Cervical Neck Muscles.

TABLE V.

REACTION TIMES (FIGURE 14) OF CERVICAL MUSCLES IN M/SEC

		SUBJECTS		
Cervical Muscle Actions	Trials	FAY01	MAZ03	MAZ02
Flexor Muscles	1	80	200	150
" "	2	ND	ND	160
" "	3	ND	190	160
Extensor Muscles	1	90	240	ND
" "	2	ND	190	ND
" "	3	140	240	ND

No Data (ND): Often due to weight drop problem which has been corrected, or to subject's resting EMG being too active prior to weight drop.

Human Use Committee of the University.

Cervical Muscle Strength Tests. Two subjects gave excellent data on the cervical muscle strengths (Table VI). These values are 3 second, time averaged, isometric values in the neutral position. An illustration of actual output data from the force transducer is presented in Figure 16. What is clearly evident is good repeatability and sensitivity. In general, this procedure appears to be quite reliable and easy to administer. Once again, later digital integration of the force data obtained will give even better measurement accuracy.

Estimating Muscle Forces During Head Jerk Tests. One of the desirable inputs needed to improve present biomechanical models of whiplash is not only the response time latency of the cervical muscles, but also the dynamic force outputs of these muscles. We are hopeful of developing some initial estimates of these forces. This will be done by first establishing the relationship between integrated EMG levels and specific levels of isometric force output for each person. Figure 16 illustrates the relationship using EMG amplitude for maximum force outputs. Figure 17 depicts the same, but for chosen submaximal efforts (the force output has been offset each time to allow a precise reading on the scale). With such a calibration type relationship (EMG amplitude/pound of muscle force) for each person, the EMG's obtained during the dynamic head jerk testing can be converted to pounds of force (or torque) to stop the head motion. At this time this appears to be feasible. Additional data and the resulting digital integration of the EMG's will be necessary to completely verify this technique. Hopefully this will be completed during the next quarter.

Head C.G. Displacement During Head Jerk Tests. Another dimension of the dynamic head jerk tests is the actual head movement to the specific

TABLE VI.
CERVICAL MUSCLE STRENGTHS (POUNDS)

Cervical Muscle Actions	Trials	SUBJECTS FAY01	MAZ03
Flexor Muscles	1	20	29
" "	2	21	29
" "	3	ND	30
Extensor Muscles	1	32	26
" "	2	35	26
" "	3	ND	23

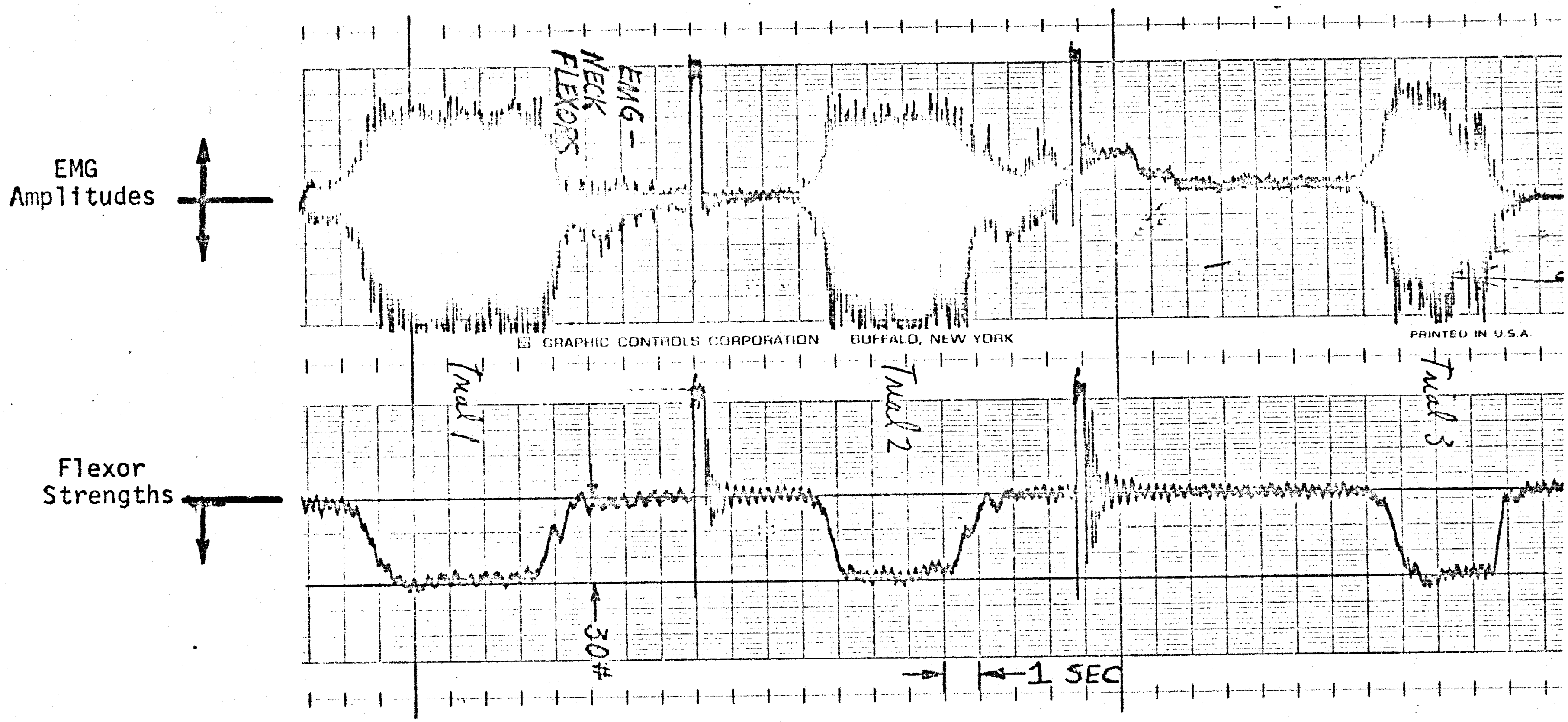


Figure 16. EMG and Muscle Force Data During Flexor Strength Tests--Subject MAZ03

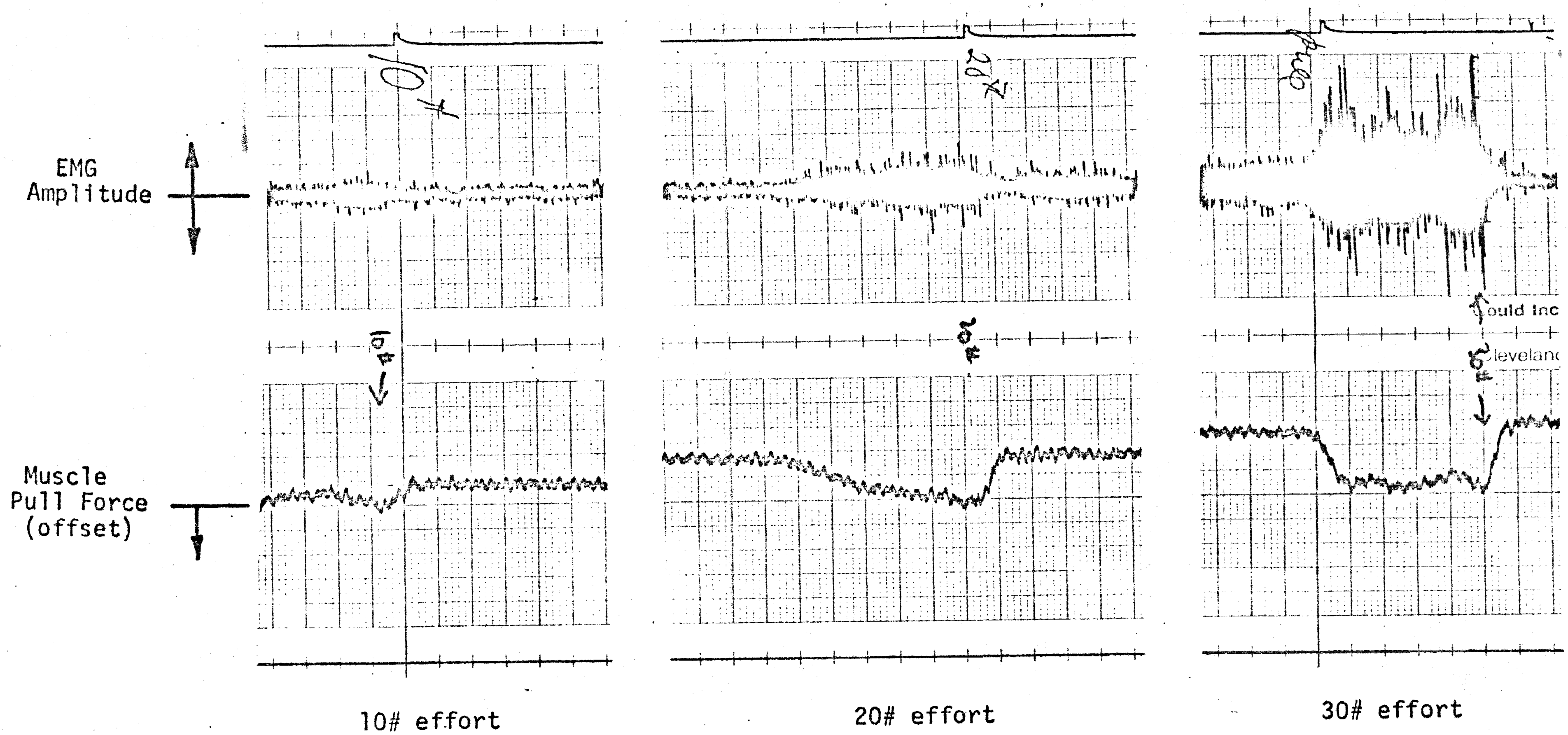


Figure 17. Data Illustrating Relationship Between EMG Amplitudes and Muscle Efforts.

impulse loads used. This can be obtained by two means. One method involves double numerical integration of the acceleration data. Since two axes of acceleration data are being recorded, this is a good procedure and will be operationally tested with the subjects and computer programs involved in the next quarter's efforts. A second method of measuring head motion is to simply measure it directly. This has been accomplished in the initial subject testing phase using the displacement transducer attached to the pulley over which the weight holding cable connects. The data thus obtained reflect directly the head motion, since the cable was taut when the weight was released. The data are summarized in Table VII for the four subjects tested.

The displacement data indicates a potential subject variance, as well as acceptable repeatability for the low impulse force loadings used. With a larger force loading, (approaching one G) even better measures of individual variance are expected.

TABLE VII.
HEAD C.G. DISPLACEMENT WITH APPROXIMATE
0.2 G PEAK ACCELERATION

Direction of Motion	Trials	SUBJECTS FAY01	MAZ03	MAZ02	MAY01
Flexion	1	5	3	2-	2
"	2	4	ND	ND	2
"	3	4	4	ND	ND
Extension	1	2.5	3	2	3
"	2	3	3	2-	2
"	3	ND	4	2-	3

Displacement in cm.

III. WORK TO BE ACCOMPLISHED DURING THE NEXT REPORTING PERIOD JULY 1 THROUGH SEPTEMBER 30.

The instrumentation, fixtures and equipment necessary to conduct this study have now been installed and the techniques checked out. Preliminary analysis of the data to date indicates that further modification of the reaction time techniques will be required. Some changes in protocol and techniques will also be anticipated during the next period as they are "debugged" in application. However, we are now able to proceed with Phase II subject measurements as indicated in Table VIII, and the emphasis during this time will be to collect measurement data. At the same time literature search and retrieval, where pertinent, will be conducted, as well as further data analysis to ensure that the various measurement techniques being utilized are resulting in valid data.

The primary measurement problems identified for resolution early in the next quarter are as follows:

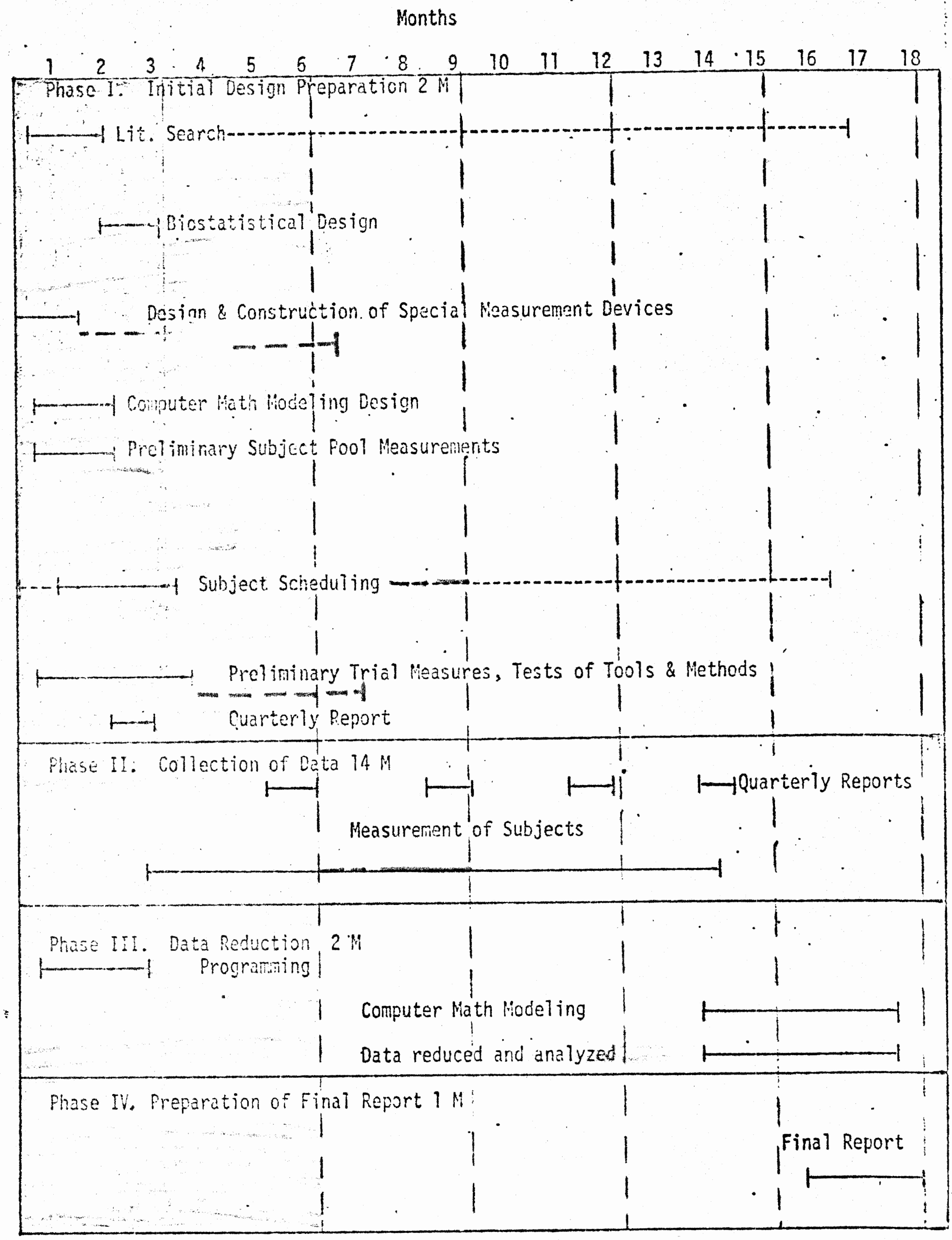
a) a larger controlled head acceleration (nearer the 1 G desired) must be obtained to provide good muscle reaction time data and dynamic muscle force reactions and

b) a more reliable accelerometer calibration and measuring system is needed to provide better head displacement data.

In addition, immediate attention must be given to combining existing computer algorithms into a data analysis system which will automatically evaluate the data described in this report.

TABLE VIII.

PROGRAM SCHEDULE



Indicates activities Projected for Period July 1 - Sept. 30
Portion of Program Completed

It should be noted that work capability during the next reporting period may also be influenced by our ability to quickly replace a key research assistant after July 1. This assistant had been primarily responsible for scheduling subjects, taking the x-rays and anthropometry, and assisting with the other measurements, and had been specially trained during the past five months in procedures and techniques relative to this program. Negotiation for an experienced x-ray technician replacement is under way and should be completed within a few days; however, if we are unsuccessful in obtaining this individual and have to train another research assistant in these techniques our progress may be expected to be adversely affected.

IV Bibliography
see whiplash bib